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Load–frequency control of interconnected power system with governor backlash nonlinearities

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ABSTRACT

In this paper, the stability-equation method is applied to the analysis and design of an interconnected power system with governor backlash nonlinearities. The considered system is a nonlinear multivariable feedback control system. The governor nonlinearities tend to produce a sustaining oscillation in area frequency and tie-line power transient responses. Most conventional linear design techniques are usually unable to find the sustaining oscillation in design phase and need simulation verifications to check the validations after designs. However, the proposed method can consider effects of nonlinearities in the design phase. Some nonlinear design techniques need parameters optimization method by Lyapunov theorem or Integral of Square Errors (ISE) criteria. They are effective. However, they need large computation efforts. The proposed method can choice frequency bias parameters and integrator gains of supplementary controllers for avoiding the oscillation or reducing the amplitude of the oscillation to be acceptable. Simulation verifications show that the proposed method can provide a simple and effective way for the considered system.

1. Introduction

For reasons of economy and system reliability, neighboring power systems are interconnected, forming an augmented system referred to as "power pool". The various areas are interconnected through tie-lines. The net power flow on the tic-lines connecting a system to the external system is frequently scheduled by a priori contract basis. The tie-lines are used for contractual energy exchange between areas and provide inter-area support in case of abnormal conditions. Area load changes and abnormal conditions, such as outages of generation, lead to mismatches in frequency and scheduled power interchanges between areas. These mismatches have to be corrected through a Load–Frequency Control (LFC). The load–frequency control is based on an error signal called Area Control Error (ACE) which is a linear combination of net-interchange and frequency errors. The conventional control strategy used in industry is to take the integral of ACE as the control signal [1–14]. The control purpose is to reduce the frequency and tie-line power errors to zero in the steady state.

Many decentralized control strategies; e.g., variable structure controls [5–7], PI/PID and Fuzzy controls [9–14], have been employed in the design of LFC for interconnected power systems. Among the various types of decentralized LFC, the most widely employed is the simple conventional control. The conventional control for LFC is still popular with the power industries because of their simplicity, easy realization, low cost, robust and decentralized nature of the control strategy. It has also been shown that there is no significant advantage in using the more complex controllers over the conventional controllers [9–11]. The conventional proportional plus integral control strategy, which is widely used in power industry, is to take the integral of ACE as the control signal.

It is well known that many LFC scheme does not yield adequate control performance with consideration of the system nonlinearities such as governor deadband or generation rate constraint [1–4]. Governor deadband (GDB) nonlinearities tend to produce an unexpected sustaining oscillation in area frequency and tie-line power transient responses. Avoiding sustaining oscillation or reducing the amplitude of the sustaining oscillation is expected. Most conventional linear design techniques [5–14] need digital simulations to check effects of nonlinearities after controller designed. The nonlinearities considered in the design phase are expected. Some nonlinear design techniques need parameters optimization method by Lyapunov theorem [1–3] or Integral of Square Errors (ISE) criteria [4]. They are effective. However, they need large computation efforts. Simple and effective ways to evaluate effects of nonlinearities are expected. This is the motivation of this paper.

In this paper, the stability-equation method [15–17] is used to analyze and design the considered system. The considered system is a nonlinear multivariable feedback control system. Harmonic-balance equations and the characteristic equation [18–21] are

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